MONTHLY WEATHER REVIEW

Editor, EDGAR W. WOOLARD

Vol. 68, No. 7
W. B. No. 1300

JULY 1940

Closed September 4, 1940
Issued October 17, 1940

NIGHT RADIATION AND UNUSUAL MINIMUM TEMPERATURES NEAR NEW ORLEANS, LA.

By W. F. McDonald

[U. S. Weather Bureau, New Orleans, La., April 1939]

On the morning of November 30, 1938, after a clear calm night attending a center of moderately high pressure over the middle Gulf coast, a minimum temperature of 43° F. was recorded, 76 feet above ground, at the New Orleans Weather Bureau office. On the same morning at Belle Chasse substation, 5½ miles southeast of the Weather Bureau office, the minimum temperature at 5 feet was 18°, a difference of 25° between the two stations. The difference on the preceding morning was 24°, with 40° at the Weather Bureau and 16° at Belle Chasse.

The Belle Chasse weather station was established in the summer of 1935 in connection with an intensive experiment in artificial heating for protection of citrus and high-value winter vegetable crops. Fourteen authentic cases in less than 4 years since the beginning of these records show minimum temperatures at Belle Chasse 20° or more below those recorded on the same dates at the Weather Bureau office. The difference in sea-level elevation is about 80 feet. Records are obtained from standard Weather Bureau instruments, with three sets of maximum and minimum thermometers and two thermographs in use at Belle Chasse in standard Weather Bureau shelters.

The area in which this station is located lies within a huge loop of the Mississippi River, about 7 miles long and of similar breadth. The main river levees surround the tract on three sides; the fourth is bounded by a drainage levee. Land slopes are very slight. The point of observation is near the middle of the area and the ground there is approximately 1 foot above sea level with a slight slope upward toward the river, where elevations are somewhat more than 10 feet in places, but the top of the main levee line is about 25 feet above sea level. The drainage levee crossing the open side of the river bend is lower, its top being about 12 feet above sea level.

The soil throughout the tract consists of the usual heavy black delta silt, known locally as "gumbo." No great fraction of the area is under cultivation; much of it is covered by dense thicket or forest but the whole area is artificially drained. The flat basin enclosed by levees is undoubtedly an ideal place within which to collect a shallow pool of cold air as the result of loss of heat by radiation when very still, clear night conditions prevail.

The extraordinary difference of 25° between minima in the two exposures separated by less than 6 miles of horizontal distance, and only 80 feet in sea-level elevation, is (so far as the present writer can discover in the available literature) unparalleled in meteorological records. The case therefore deserves a full report and discussion which it is the purpose of this paper to present. Records of several other ground-level stations in the flat, densely overgrown Mississippi delta will be added, for the light they throw on the factors operating to produce the conditions described.

Before proceeding to more detailed discussion of the Belle Chasse temperature records, it may be well to survey briefly some reports of other investigations in the same field.

Cox (2) studied records from the cranberry bogs of Wisconsin and found extreme differences of 14° to 16° in the minimum temperatures observed at stations separated by only about 700 feet. Careful examination of his data shows, however, that the higher of these temperatures occurred within a standard shelter 5 feet above sandy upland, while the lower readings were obtained from an unshielded minimum thermometer exposed a very short distance above moss in the bog.

Lack of shielding introduces into those records from 3° to 8° of incompatibility and the reported differences in temperatures must be reduced accordingly. Furthermore, it has more than once been shown (**6, 7**) that a sharp inversion of temperature amounting to as much as 6° to 8° often exists within 5 feet of the ground surface under active night radiation. This effect is much more strongly represented in the cranberry-bog records cited by Cox than in the Belle Chasse records under discussion inasmuch as the lower bog station was in the air layer within which this ground surface inversion exists whereas Belle Chasse observations are made at about 5 feet elevation and thus avoid most of the effect of the low surface inversion.

In another paper (**3**) Cox discusses thermal belts in the Carolina highlands and he there reports a maximum difference in night temperatures amounting to 31° F., but the stations under comparison differed by 1,000 feet in elevation. Air drainage rather than simple cooling by radiation enters strongly into these highland situations, but this factor must be almost completely absent from Louisiana delta conditions due to the lack of topographic relief.

Young (**8**) reports a variation of 28° in adjacent records of minimum temperature at stations separated by only a half mile in the Pacific-coast region, but there was a difference of 225 feet in ground elevation at the points involved. Here also, clearly, there was pronounced opportunity for air drainage to affect the situation.

A few years ago Dyke (**4**) studied local variations in minimum temperatures observed within the city of New Orleans, comparing the records obtained at the Weather Bureau office with those taken in Audubon Park, 5 feet above ground. He found the greatest difference in minima to be 16°. The same author examined records from the Weather Bureau office in Houston, Tex. (almost

300 feet above ground), and those from a station having standard ground exposure in open country at Harrisburg, Tex., about 35 miles away, but found no difference greater than 17° in minimum temperatures during the period studied.

A number of situations can be cited in which variations of 10° to 18° can be found between closely adjacent situations, especially between roof exposures at mid-city Weather Bureau stations as compared with nearby suburban records obtained from ground exposures, but no other case has been found with so much difference where air drainage is excluded.

Table 1 contains details for 14 dates on each of which the minimum temperature at Belle Chasse was 20° or more below that at the Weather Bureau office in New Orleans on the same morning. The average difference for these 14 dates is 22°. Shown also in this table are records for two additional ground level stations, Delta Farms and Houma, both located in the coastal delta region. Climatic and topographic conditions are much alike at all stations named. Delta Farms, like Belle Chasse, has a ground

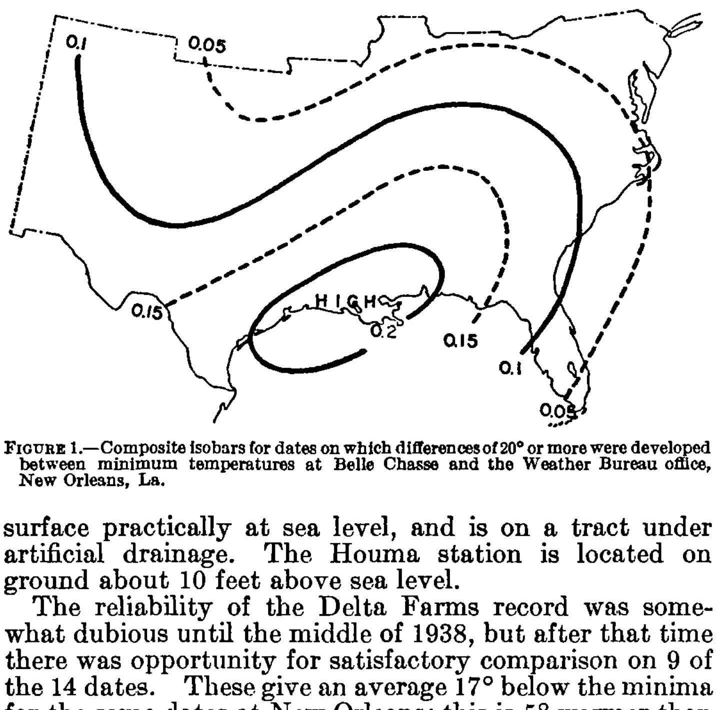

FIGURE 1.—Composite isobars for dates on which differences of 20° or more were developed between minimum temperatures at Belle Chasse and the Weather Bureau office, New Orleans, La.

surface practically at sea level, and is on a tract under artificial drainage. The Houma station is located on ground about 10 feet above sea level.

The reliability of the Delta Farms record was somewhat dubious until the middle of 1938, but after that time there was opportunity for satisfactory comparison on 9 of the 14 dates. These give an average 17° below the minima for the same dates at New Orleans; this is 5° warmer than the average for Belle Chasse. The readings for Houma are taken on a cane plantation, and the soil of the area is a sandy loam. Good records at this station extend over the entire period covered by table 1, and the average depression of these minima in comparison with New Orleans is 16°, a difference almost identical with that shown for Delta Farms.

Houma lies 45 miles southwest of New Orleans, and Delta Farms is about halfway between that point and New Orleans. Both stations are located where there is no forest influence in the immediate surroundings. While unusually cold conditions are shown to develop with some frequency over a rather wide area near New Orleans, the most intense effects occur at Belle Chasse, which on some of these occasions had the lowest temperature officially recorded in the entire State of Louisiana on the given morning.

In order to have a still more complete setting for these selected occasions of unusually large abnormality in temperature, the whole period of the Belle Chasse records (44 months) was very carefully surveyed and the daily differences in minimum temperature as related to New Orleans were computed and tabulated.

Results are given in table 2, which shows Belle Chasse minima nearly 8° below those for the Weather Bureau office, for the year as a whole. The average monthly differences vary from 4° in January and February to 9° in October. Belle Chasse temperatures are 10° or more below the Weather Bureau office readings on 30 percent of all the days of record; and 8 percent of the time the difference is 15° or more. The occasions when Belle Chasse is 15° or more colder than New Orleans are strongly grouped in the last 3 calendar months, occurring about 1 day out of 5 in the period from October to December, inclusive. Ten of the fourteen cases of 20° differences listed in table 1 occurred in 2 months, October and November; all lie between October 19 and March 19.

Table 2 reveals a double seasonal arrangement, however, with lower values at midwinter and midsummer. (See fig. 3.) Higher values occur in 2 periods of 4 or 5 months each, centered roughly on spring and autumn. This is particularly evident in the columns showing the percentage of cases with 10° and 15° of depression in the Belle Chasse daily minima.

The general background for the more pronounced cases of cooling at Belle Chasse (listed by dates in table 1) can be best indicated by composite isobars from daily weather maps attending these occurrences. This composite is represented by figure 1, which shows the significant type condition, namely, a high-pressure area centered over southern Louisiana.

The individual weather charts from which figure 1 is generalized are more often characterized by a high-pressure ridge than by the localized center shown on the composite, but in nearly all cases the axis of the ridge lay east-west or northeast-southwest with the center line passing through Louisiana. It goes without saying that the individual high-pressure areas involved in these situations are of the continental and not the marine type. The most brilliantly clear skies at New Orleans occur with the advent of large masses of Pc air and winds of high velocity in the free air from a direction definitely north of west.

Another feature of the general weather situation should be mentioned. The extreme development of differences in night temperature at Belle Chasse as compared with New Orleans does not occur immediately upon establishment of true cold wave conditions, but is usually found on the second or even the third night of the cold spell, when temperatures at New Orleans have passed the lowest point. This of course is due to the part played by low wind movement in producing these local differences of temperature. It is only the calm conditions attending the central area of the anticyclonic formation that favor stratification of cold air at the earth's surface under clear night skies, which is necessary to establish the strong inversion of temperature involved in the situation.

To illustrate how completely the movement of wind at the low-level station enters as a control on radiation minima, two composite thermograph traces are shown in figure 2. These are somewhat idealized and simplified, but in character well represent the march of temperature on clear nights. The first section of this figure depicts the maximum effect of undisturbed radiation with very low wind movement and shows how under such conditions the temperature curve for Belle Chasse practically doubles the range of that for the Weather Bureau office. The lower section of this figure shows at first the regular down-curve that is typical of the simple cumulative effect of outgoing radiation as it increases from early afternoon. The difference in temperature between thermograms at the two stations increases steadily until an increase in wind velocity to 4 or 5 miles per hour occurs at Belle Chasse; when this happens the temperature immediately rises there and the extreme difference in minima cannot thereafter be established, even though wind movement should again

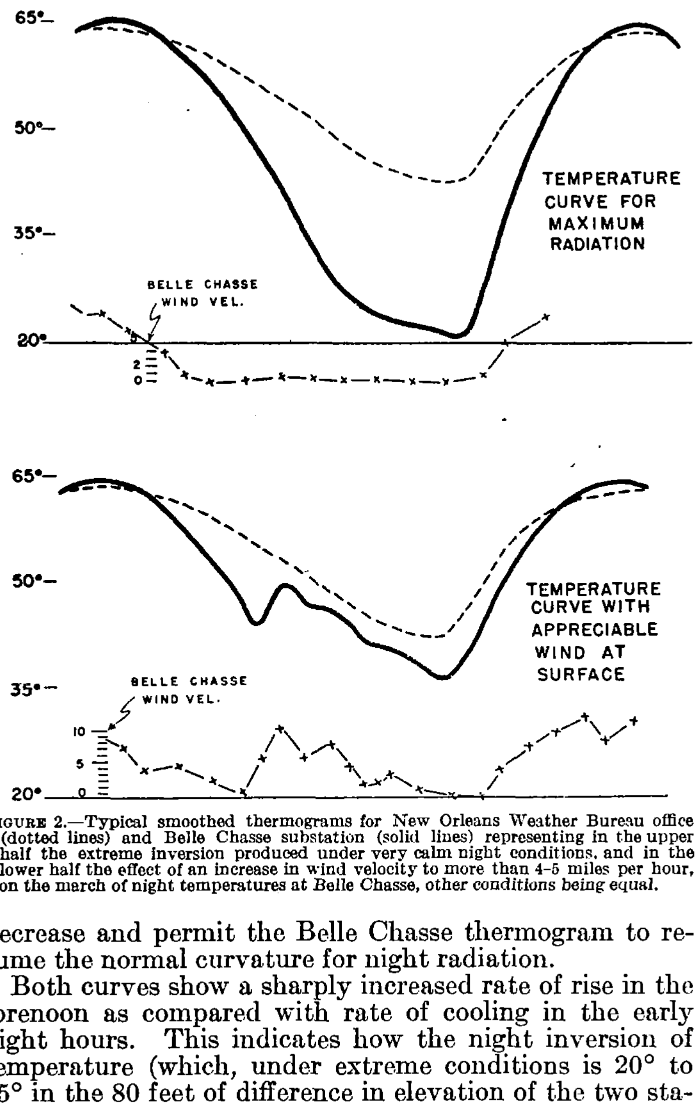

FIGURE 2.—Typical smoothed thermograms for New Orleans Weather Bureau office (dotted lines) and Belle Chasse substation (solid lines) representing in the upper half the extreme inversion produced under very calm night conditions, and in the lower half the effect of an increase in wind velocity to more than 4-5 miles per hour, on the march of night temperatures at Belle Chasse, other conditions being equal.

decrease and permit the Belle Chasse thermogram to resume the normal curvature for night radiation.

Both curves show a sharply increased rate of rise in the forenoon as compared with rate of cooling in the early night hours. This indicates how the night inversion of temperature (which, under extreme conditions is 20° to 25° in the 80 feet of difference in elevation of the two stations) breaks down with the first inception of morning turbulence, and warming proceeds by mixing combined with direct insolation. The new maximum is thus reached in about half the time required to establish the previous minimum temperature, indicating that mixing, under extreme conditions, can be as effective as insolation in the warming process.

Two questions are raised by these observations. These questions are: (*a*) Why are radiation minima at Belle Chasse 5° to 6° lower in the average than those at the similarly situated stations, Delta Farms and Houma; and (*b*) What is the explanation for the double seasonal period in radiational influence revealed by the monthly survey of difference in table 2?

In considering the first, we note that the high levee almost surrounding the area in which Belle Chasse is located has no counterpart at either of the other ground-level stations. This levee is certainly a significant factor in the observed localization of low-temperature effects near Belle Chasse, acting doubtless to conserve a pool of cold air.

There are, however, other physical differences in the environment of the three stations compared, that may be equally or perhaps even more significant. Belle Chasse stands in a locality that is, in the main, overgrown with high vegetation including much low forest of almost jungle density. In contrast, Delta Farms is surrounded by low-growing marsh vegetation, and at Houma the condition of the adjacent cane fields ranges from a bare cultivated surface in the early part of the year to the dense 10-foot growth of mature cane prior to harvest, near the end of the year.

Several investigators (**1, 5**) have called attention to the part played by different types of vegetative cover in producing variable effects upon night radiation and minimum air temperatures, but the role played by cover as distinct from type of soil has seldom been given any special emphasis.

Some unpublished temperature observations made by Arceneaux and Lauritzen at the United States Cane Experiment Station, Houma, La., which the present writer has been permitted to examine, indicate very strongly that night radiation at the level of the tops in full-grown stands of sugarcane produces on very still clear nights a peculiar stratification of the air, such that the temperature at the upper level is *lower* than that at the ground surface beneath. Later in the season, when the cane leaves have been killed by frost, this effect is no longer observable; at that time the lowest temperature within the same stand of cane occurs, not at the top but at the base of the plant.

Cornford (1) cites data (in his study of night temperatures in Britain) that directly confirm these observations by Arceneaux and Lauritzen. He states, for example, with reference to a stand of wheat, that "at 3 feet high it

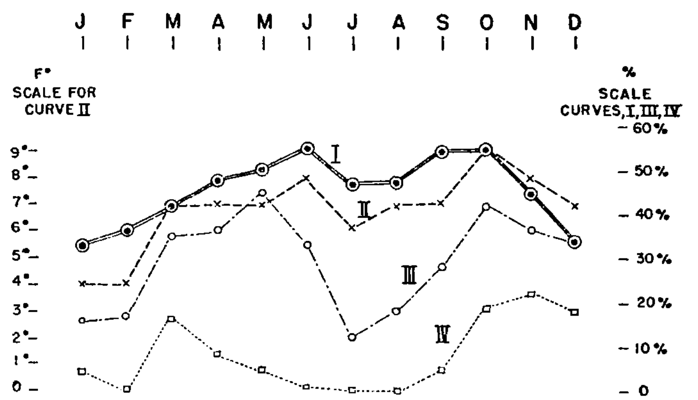

FIGURE 3.—Curve I: Composite of (*a*) the percentage of observations at New Orleans, La., showing depression of the wet bulb amounting to 12° or more, with (*b*) monthly percentage of total hours between sunset and sunrise (night hours) based on total hours in the month. Curve II: Mean daily difference between minimum temperatures at New Orleans and Belle Chasse. Curves III and IV: Percentage of days with minimum 10° or more colder (III), and 15° or more colder (IV) at Belle Chasse as compared with New Orleans Weather Bureau office records.

is colder over the wheat than over the (adjacent) bare soil. Between the stems of wheat the air is relatively warm." The temperature differences shown by his detailed data range from 0.7° to 1.7°.

The practically uninterrupted surface of dense green vegatation may therefore be assumed to act as the plane of maximum night cooling. Such green surfaces probably approach in effectiveness the rate of black body radiation. At Belle Chasse dense vegetation closely surrounds the small acreage of cleared land on which the observing station is located, with an average top height estimated at 15 to 35 feet above ground level. If these tops become the coldest surfaces under night radiation there must be at least a slight tendency for the air from those levels to settle down into the adjacent clearing in the manner described in Cornford's studies (**1**). With very light air movement the coldest air should thus accumulate near the point of observation, located on agricultural land having relatively low cover. Such effects could not be expected in equal degree at Houma or Delta Farms due to lack of similar contrast in level of the vegetative surfaces from which nocturnal radiation proceeds.

The Louisiana delta region supports vegetation in remarkable profusion. Native plants are only partially deciduous and the rest period for annuals and deciduous perennials is quite short, confined mainly to the 2 months, January and February. When greenery is fully established there is hardly a square foot of overgrown area through which radiation can proceed directly to or from the soil surface. The usual influence of soil type and soil moisture as affecting night temperatures is thus lacking and there is instead the far more uniform and in general more effective radiation from an unbroken expense of green leaf surfaces acting somewhat like well insulated black to bring about nocturnal temperatures lower than similar weather situations can produce in less fertile regions.

It is interesting to note that the thermograms from Belle Chasse frequently show a slight dip in temperature just about sunrise, coincident with the first increase in air movement following a calm night. This drop in temperature appears to result from mixture of the air at the level of the recording thermometers (about 5 feet) with a colder stratum from some adjacent level, but whether from a lower or a higher source it is impossible with the data in hand to determine.

In seeking for the solution of the second problem—that of the double seasonal curve in frequency of larger temperature differences at Belle Chasse shown by table 2—probable explanations must be more tentatively advanced. The degree to which minimum temperatures are depressed depends not only upon the character of the radiating surface, heretofore discussed, but also upon the relative proportions of night and day. The longer nights of autumn and winter offer opportunity for a larger cumulative loss of heat by radiation than will be possible in the shorter nights of spring and summer. Hence, if this were the only influence at work, the major inversions in temperature (which really govern the observed differences between records at Belle Chasse and in New Orleans) should be commonly noted in autumn and winter, when there should be a peak in frequency, with decreased frequency in spring and summer. Instead we find the principal minimum of frequency in midwinter and a secondary peak in the spring and early summer.

This might be partially attributed to loss of green cover by winter-killing during the coldest time of the year, with a rapid recovery in spring. The greater differential cooling at Belle Chasse in summer (when the average difference in daily minimum as compared with New Orleans amounts to 6° or 7° in contrast with the value of 4° in midwinter) argues for the effectiveness of green vegetation in producing this midsummer excess. However, this line of reasoning does not explain the spring peak, as there is no peak in vegetative cover at that season.

Some additional factor or factors must therefore be sought having a variability in the year similar to that of the data under examination. Recalling the fact that the major temperature differences were recorded when the region was under control of air masses of polar continental origin, which are characterized by low specific humidity, it seemed logical to search for a practical index to the incidence of dry air masses at the various seasons of the year.

Fortunately, the depression of the wet bulb, as recorded in 35 years of observations at the New Orleans Weather Bureau office, had already been tabulated with the percentage of cases with depression of 5° or more, 8° or more, 12° or more, etc., worked out by months. Study of these data shows a double periodicity in the seasonal march of larger values, and pronounced spring and autumn maxima.

A curve was finally developed having a reasonable basis in probable causal relationship and showing a seasonal distribution of magnitudes significantly resembling those given for cooling at Belle Chasse (table 2). It was obtained by an empirical combination of two percentage figures. The first element, which provides a numerical index for proportional length of night compared to day, is the percent of total hours in each month that lie between sunset and sunrise. (This is simply the complement of the "total possible hours of sunshine" divided by the "total hours in the month.") The second element is that already described, namely, the percent of observations at New Orleans with depression of the dewpoint amounting to 12° or more. The simple means of these two monthly percentage values have been plotted, together with the monthly items from several columns of table 2, to produce figure 3, where the similarity in the various curves may be tested by inspection.

It appears that dryness of the atmosphere is quite as important as length of night in lowering noctural temperatures near the earth's surface.

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TABLE 1.—*Comparison of minimum temperature observations at Belle Chasse, La., and 2 additional ground-level stations, with the minimum at New Orleans Weather Bureau office as the basis for comparison, on 14 dates when Belle Chasse was 20° or more below New Orleans*

Date	Minimum temperature, New Orleans	Belle Chasse		Delta Farms		Houma	
		Minimum	Difference	Minimum	Difference	Minimum	Difference
	°	°	°	°	°	°	°
Nov. 30, 1935	49	29	20	?	-------	36	13
Oct. 19, 1936	64	43	21	?	-------	49	15
Dec. 23, 1936	50	26	24	?	-------	33	17
Mar. 19, 1938	68	45	23	?	-------	57	11
Oct. 25, 1938	55	32	23	36	19	39	16
Oct. 26, 1938	55	34	21	36	19	40	15
Oct. 29, 1938	59	39	20	44	15	43	16
Oct. 30, 1938	60	38	22	44	16	42	18
Nov. 10, 1938	48	26	22	34	14	32	16
Nov. 21, 1938	52	31	21	36	16	36	16
Nov. 29, 1938	40	16	24	23	17	24	16
Nov. 30, 1938	43	18	25	24	19	27	16
Dec. 6, 1938	47	23	24	29	18	32	15
Jan. 20, 1939	47	27	20	?	-------	29	18
Average depression of minimum below New Orleans	-------	-------	22	-------	17	-------	16

TABLE 2.—*Tabulation of daily differences in minimum temperature at Belle Chasse compared with those at the Weather Bureau Office in New Orleans. (All temperatures at Belle Chasse are lower than those with which they are compared.) Based on 44 months of record; 1935–39*

Month	Average monthly depression of minima at Belle Chasse	Percentage of daily observations with the minimum temperature at Belle Chasse—		
		10° or more below New Orleans	15° or more below New Orleans	20° or more below New Orleans
	°*F.*	*Percent*	*Percent*	*Percent*
January	4	16	5	1
February	4	17	0	0
March	7	35	16	1
April	7	37	8	0
May	7	45	5	0
June	8	33	1	0
July	6	12	0	0
August	7	18	0	0
September	7	28	5	0
October	9	42	19	5
November	8	37	22	4
December	7	34	18	4
Annual average	7.6	30	8	1

RADIATIVE COOLING IN THE LOWER ATMOSPHERE

By WALTER M. ELSASSER

[California Institute of Technology and U. S. Weather Bureau, August 1940]

The writer has recently developed a graphical method for the determination of radiative heat transfer in the atmosphere (1). This is a modification of the graphical method introduced some years ago by Mügge and Möller (2). In this method moisture and temperature values of a given atmosphere are plotted on a printed diagram (later referred to as Radiation Chart) and the radiative flux at any level can be obtained by evaluating an area on the chart. The results given below represent the first practical tests of our chart. A comprehensive paper covering the theory of the chart has just been published (1) and we shall therefore omit references to the theoretical foundations of this work and confine ourselves to a communication of the results.*

I. FREE AIR COOLING

We used airplane observations of free air moistures and temperatures. The stations selected (with the exception of Fort Smith, Northwest Territory) are located in two north-south cross sections over the United States. The mean values of February 1937 and of August 1937 served as basis for these calculations. The cooling calculated represents the mean cooling in layers 1 kilometer thick due to the long-wave radiation of water vapor (the cooling due to carbon-dioxide radiation is found negligible). The procedure of evaluating the cooling was as follows. First, specific humidity (with a pressure correction applied, see below) was plotted against pressure. The points were joined by a curve and the total amount of moisture between successive levels, 1 kilometer distant, was determined by means of a planimeter. These values of total moisture were then plotted against temperature on the radiation chart. It is usually possible to plot, on the same chart, curves corresponding to several or to all levels of one station. The area contained between curves representing successive levels measures the heat loss of the layer between them; this loss divided by the heat capacity of the layer gives the net cooling.

*Part of the calculations was carried out by A. C. Gibson of the U. S. Weather Bureau, now at Jacksonville, Fla.

There is still a certain doubt about the manner in which the air pressure affects the radiative properties of water vapor. According to a theoretical formula (3) the absorption should be proportional to the pressure, while F. Schnaidt (4) derives from measurements of G. Falckenberg (5) the result that the absorption is proportional to the square root of the air pressure. The latter view is sustained by other, yet unpublished, experiments carried out by John Strong at the California Institute of Technology. We therefore used the square root pressure correction in our computations.

The figures in table 1 represent mean values of the cooling in layers 1 kilometer thick. It is to be understood that these layers have nothing to do with the division of the atmosphere in layers in the manner of Simpson (6). The latter division originates from a method of approximation where differentials are replaced by finite differences. Our figures, on the other hand, represent rigorous solutions of the differential equations of radiative transfer, once the absorption coefficients of water vapor are given. It would be possible to calculate the "local" cooling at any given level, but the determination of the mean cooling of a layer of reasonable thickness is less laborious and also much more accurate. The values given in table 1 are in degrees centigrade per day.

All the cooling values contained in table 1 are plotted in figure 1 with the decadic logarithm of the specific humidity as abscissa. The oblique line represents the empirical relation

$$(\Delta T)_{day} = 1 + 2 \log_{10} w \tag{1}$$

The two dashed lines are set off from the main line by 0.4° on each side. It is seen that the large majority of the points falls within these boundaries. The major deviations seem to occur in the lowest kilometer; the points representing these layers are indicated by rings in figure 1. The cause of this decrease in cooling is presumably to be found in the relatively lower mean temperature of the lowest kilometer due to the influence of the nocturnal